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by

Yu.V. Afanas'yev, O.N. Krokhin

EDITED TRANSLATION

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GAS-DYNAMIC THEORY OF THE EFFECT OF LASER EMISSION ON CONDENSED SUBSTANCES

Yu.V. Afanas'yev, O.N. Krokhin

Introduction

The problem of the interaction of optical quantum generators [lasers] with a substance includes a wide range of questions, beginning from the elementary quantum processes (multiphoton absorption) and ending with the study of macroscopic phenomena appearing with the action of the laser emission on the absorbing or translucent media. Belonging to the macroscopic phenomena, besides the nonlinear optics, is, first of all, the phenomenon of the breakdown of gases under the effect of the focused laser emission ("flash"), the formation and heating of the plasma up to thermonuclear temperatures, and also the dynamic effects which appear with the action of powerful flows of laser emission onto condensed substances.

The indicated phenomena up to the present time are the subject of numerous studies, both experimental and theoretical. The interest in these studies is caused mainly by the possibility of studying the behavior of different substances in conditions of powerful electromagnetic fields (up to 10^7-10^8 V/cm) and high densities of radiation fluxes (up to 10^{12}-10^{13} W/cm^2).

There is great interest also in a number of practical questions connected with the use of laser for the industrial treatment of metalls and with their use in chemistry, thermophysics, biolo-

biology, and medicine.

Up to the present time from the listed effects, the most comprehensively studied has been the phenomenon of the breakdown of gas, i.e., the formation of a "flash" in the focus of a laser beam. Examined in detail in a survey article of Raiser [1] are the different mechanisms of the appearance of a flash, and theoretical and experimental results are given. In this article there are references to practically all the known works in this direction.

The idea of the possibility of the obtaining of a high-temperature plasma by means of a focused laser emission was first formulated in the work of Basov and Krokhin [2]. Later the indicated possibility in a somewhat more exapanded form was investigated in the work of Dawson [3].

Much experimental material has also been accumulated in the field of investigation of processes appearing with the action of powerful emission of lasers on condensed substances. Works in this field have essentially been developed in two directions: studies of the effect of laser emission on translucent substances (dielectrics) and the study of effects taking place with the interaction of the laser emission with greatly absorbing substances, mainly metals.

It should be noted that the physical processes in these two indicated cases are fundamentally different only in the region of relatively small densities of flows of the incident radiation. With an increase in the density of the radiation flux, the dielectric also becomes opaque, and the phenomena appearing in both cases prove to be close in their physical nature.

In this work we will be interested in the processes which are observed with the action of the laser emission in a wide range of densities of flows on the opaque condensed substances.

As was already indicated, there is a great number of experimental works devoted to this question. We will examine some of them in detail below (see section 1). However, in this case the rate of the experimental works considerably lags the theoretical studies. Leaving the discussion of the published theoretical works prior to section 1, let us note that at the present time

only several such works are known [4-7]. In all the indicated works the investigation is conducted within the framework of the nonstationary theory of thermal conductivity in a condensed substance.

As it will be shown below, the use of the equation of thermal conductivity with radiation of the process of the interaction of the laser emission with the opaque solid substance proves to be a good approximation to the processes actually appearing in this case in the region of relatively small densities of the flows substantially lower than 10^5-10^6 W/cm^2.

With an increase in the density of the flow of radiation falling onto the surface of the condensed solid, there occurs a sharp change in the aggregate state of the substance which absorbed the radiation with the subsequent surge of the new phase (the formation of the "flare") owing to the appearing pressure gradients. In this case the final state of the ejected substance depends on the mean free path of the incident radiation in the condensed solid and on the magnitude of density of the radiation flow. It is physically clear that in this case the model connected with the mechanism of thermal conductivity is insufficient for a description of the examined process, and the problem must be solved by taking into account the motion of the substance which absorbed the radiation.

Furthermore, at sufficiently high densities of the flows, the magnitude of the energy of radiation transmittable in a solid owing to the thermal conductivity proves to be, as will be shown below, negligible as compared to the energy which is carried away by the ejected substance.

Thus the problem being considered in the region of densities of flows of radiation greater than the magnitude of 10^6 W/cm^2 is purely a gas-dynamic problem on the evaporation of a substance under the effect of radiation.

Let us note that similar problems appear in the case of the evaporation of the substance under the effect of radiation in gas-discharge lamps [8]. Furthermore, a similar situation takes place in MK-generators when as a result of the finite conductivity of the

material of the cylinder compressing the magnetic flow, a considerable role is played by the "surface explosion" of the layer of metal due to the release in it of Joule heat, which exceeds the energy of sublimation [9]. This phenomenon, as is indicated in [9], can be examined on the basis of the solution of gas-dynamic solutions.

This article is devoted to the theoretical study of the gas-dynamic processes appearing with action on the condensed opaque substance of the laser emission in the region of densities of flows greater than the magnitude of 10^6 W/cm^2.

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